

A DEVICE IN THE STATOR OF A ROTATING ELECTRIC MACHINE AND  
SUCH A MACHINE

5 The present invention relates to the area of rotating electric machines such as synchronous machines, and also dual-fed machines, applications in asynchronous static current converter cascades, outerpole machines and synchronous flow machines and is intended to be used at high voltages, by which is implied electric voltages in excess of 10 kV. A typical operating range for the machine according to the invention may be from 36 to 800 kV.

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The invention relates to a stator winding in a rotating electric machine of the type defined in the preamble to claim 1.

15 Since the stator winding in the machine, according to the invention, consists of high-voltage insulated electric conductors, in the following termed cables, with permanent insulation similar to that used in cables for transmitting electric power (e.g. PEX cables), the voltage of the machine may be increased to such levels that it may be connected directly to the power network without an intermediate transformer. These voltage levels reaching the level of the power network may be  
20 in the range of 130-400 kV and up to 800 kV or higher. This enables the elimination of the step-up transformer and a high-current breaker, thereby enabling lower total plant cost.

25 It is known to manufacture coils for rotating machines for a voltage range of 10-20 kV.

30 However, attempts at developing a generator for voltages higher than this have been in progress for some time, as is evident from "Electrical World", October 15 1932, pages 524-525, for instance. This describes how a generator designed by Parson 1929 was constructed for 33 kV. A generator in Langerbrugge, Belgium, is also described which produced a voltage of 36 kV. Although the article also speculates on the possibility of increasing the voltage levels, development of the concepts upon which these generators were based ceased. This was primarily due to deficiencies in the insulating system where several layers of varnish-  
35 impregnated mica foil and paper were used.

In A report from the Electric Power Research Institute, EPRI, EL-3391, from April 1984 an exposition is given of the generator concept in which a higher voltage is achieved in an electric generator with the object of being able to connect such a generator to a power network without intermediate transformers. The report deems such a solution to offer satisfactory gains in efficiency and financial advantages. The main reason that in 1984 it was considered possible to start developing generators for direct connection to the power network was that by that time a superconducting rotor had been developed. The considerable excitation capacity of the superconducting field makes it possible to use air-gap windings with sufficient thickness to withstand the electric stresses.

By combining the construction of an excitation circuit together with winding, a so-called "monolith cylinder armature", a concept in which two cylinders of conductors are enclosed in three cylinders of insulation and the whole structure is attached to an iron core without teeth, it was deemed that a rotating electric machine for high voltage could be directly connected to a power network. This solution implied that the main insulation had to be made sufficiently thick to withstand network-to-network and network-to-earth potentials. Besides it requiring a supraconducting rotor, an obvious drawback with the proposed solution is that it requires a very thick insulation, thus increasing the size of the machine. The coil ends must be insulated and cooled with oil or freones in order to direct the large electric fields into the ends. The whole machine is to be hermetically enclosed to prevent the liquid dielectric medium from absorbing moisture from the atmosphere.

All large generators are normally designed with double-layer winding and coils of equal size. Each coil is placed with the one side in one layer and the other side in the other layer. This implies that all coils cross each other at the coil ends. In high-voltage machines the slots in which the coils are placed in the stator are considerably deeper and typically have 10-12 or up to 18, and in certain cases even more winding layers. The number of coil ends is therefore large with many intersections, which complicates the job of winding and may also cause the coil ends to protrude into the air gap between stator and rotor. Another problem is the increased risk of wear at all the intersection points between the coils.

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The object of the present invention is to solve the problem of the large coil-end packages and minimize the number of intersections between the winding coils. This object is achieved by the stator winding, according to the invention, being given the features defined in the claims.

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The invention is primarily intended for use with a high-voltage cable of the type constructed from a core having a number of strand parts, a semi-conducting layer surrounding the core, an insulating layer surrounding the inner semi-conducting layer and an outer semi-conducting layer surrounding the insulating layer, and its advantages will be particularly noticeable therewith. It relates particularly to such a cable having a diameter within the interval 20-200 mm and a conducting area within the interval 80-3000 mm<sup>2</sup>. Such applications of the invention thus constitute preferred embodiments thereof.

10 The invention is described in more detail with reference to the accompanying drawings in which;

Figure 1 shows a cross-section through a cable used for the invention,

20 Figure 2 shows a part of one end of a stator having a plurality of coil ends protruding from its surface, only a few of which are included in the drawing,

Figure 3 shows in radial section one half of an alternating current generator with a stator winding according to the invention,

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Figure 4 is a schematic diagram of the winding according to one embodiment of the invention,

30 Figure 5 is a schematic diagram of the winding according to a second embodiment of the invention,

Figure 6 shows one sector of a stator lamination for a winding according to the invention,

35 Figure 7 shows a schematic diagram of the winding according to a third embodiment of the invention, and

Figure 8 shows a coil-end package seen radially from the air gap, with a winding according to the invention.

5 Figure 1 shows a cross-sectional view of a cable 101 used for the present invention. The cable 101 comprises a conductor 102 consisting of a number of strands of copper, for instance, and having circular cross section. This conductor 102 is arranged in the middle of the cable 101. Around the conductor 102 is a first semi-conducting layer 103, and around the first semi-conducting layer 103 is an  
10 insulating layer 104, e.g. PEX insulation. Around the insulating layer 104 is a second semi-conducting layer 105. In this case, therefore, the cable does not include the outer protective sheath that normally surrounds such cables for power distribution.

15 Figure 3 shows in a diametric section one half of a high-voltage generator with a stator 106, a rotor 107 and an air gap 108 between them. Figure 2 shows the inner surface 109 of the stator, facing the air gap 108. The stator 106 is provided with inwardly directed stator teeth 110 defining between them radial slots 111 to hold the cables 101 of the winding. The winding thus forms a large number of layers  
20 through the deep slots 111, which in the example shown have place for 12 cables in each enlargement 112. "Layer of the winding" in this context refers to layers at different radial distances from the central axis of the stator. "Stratum" on the other hand refers to strata of the winding at different axial distances from the end surfaces of the stator.

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It is clear from Figure 2 how the cable 101 forms coils 113 which pass axially to and fro through the stator 106 and form arc-shaped coil ends outside the end surfaces 114 of the stator. A coil thus consists of one turn of the cable through the stator. A coil group comprises the winding for one phase. The part of a coil group  
30 situated in one and the same winding layer, and the coil ends of which are situated in different strata is here designated "coil group part".

Contrary to previously known multi-strata stator windings the coils 113 according to the invention are arranged such that they do not cross each other within the  
35 same coil group part. Figure 2 shows a group part comprising, in this case, four coils 113a, 113b, 113c and 113d situated axially, one outside the other and with

substantially coinciding centres. Since the coil 113a has a larger diameter than coil 113b, which in turn has a larger diameter than coil 113c, which in turn has a larger diameter than coil 113d, these coils do not cross or touch each other. This implies that the number of slots 111 that each coil bridges before entering the stator again varies within the group part. The coil 113d thus bridges the least number of slots and the coil 113a the largest number of slots.

Winding is also performed so that, upon passage from the first slot in one direction to the second slot in the opposite direction, the cable in the coil changes position in the slot to the nearest winding layer outside it. The same thing occurs when it returns to the first slot. When all positions in the two slots have been filled, the coils produce a formation reminiscent of a spiral compressed from the sides, stretching from the air gap 108 to the stator yoke 115. The cable then passes to the next adjacent slot to form the next coil, inside or outside, in the same formation.

Figure 4 is a schematic diagram showing how the winding of a cable U1 is performed. In Figure 3 the slots 111 and positions therein have been numbered in corresponding manner to Figure 4. Contrary to the example in Figure 2, each coil group part comprises three instead of four coils. According to Figure 4 the cable U1 starts from position 1 in slot 3, changes to position 2 when it reaches slot 9, then to position 3 when it passes back to slot 3 and to position 4 in slot 9, and so on. This continues until all positions in slots 3 and 9 have been filled, whereupon the coils produced in this way together form the above-mentioned formation from the air gap 108 to the stator yoke 115. As is clear, each coil end bridges  $9 - 3 = 6$  slots. Winding is continued with the construction of a larger external coil in each turn in the formation, through the cable being conducted to position 1 in slot 2, thence to position 2 in slot 10 and back to position 3 in slot 2, and so on until position 10 in slot 10 has been filled. The coil ends here bridge  $10 - 2 = 8$  slots and the later coils will therefore be situated outside the earlier coils with substantially coinciding centres. The third coil in this group part is formed by the cable passing to position 1 in slot 1, from there to position 2 in slot 11 and then to position 3 in slot 1 and position 4 in slot 11, and so on. In this case the coil ends bridge  $11 - 1 = 10$  slots and the coils are therefore the largest in the group part and are situated outermost in the spiral. The coil group described forms the winding

for one phase in the generator. The other phases are constructed in similar manner.

Figure 5 shows a second embodiment of the winding according to the invention. Contrary to the embodiment according to Figure 4, the positions 1 and 2 are completely wound in slots 4 and 11, 3 and 12 and 1 and 14, before winding is continued with positions 3 and 4 in the same slots. Winding of these four positions then continues in additional slots. The diagram shows the windings of one phase in a three-phase winding with four coils per slot and four slots per pole and phase.

In the two winding variants described, the number of coils in each coil group part is three and four, respectively. However, the invention is not limited to this, and the number may be anything from two to over ten.

Figures 6-8 show a third embodiment of the winding according to the invention. As can be seen in Figure 6, the positions in the slots have been reversed from those in Figures 3-5 and are numbered radially inwards from the outside. As can be seen in Figure 8, the coil group parts are arranged in relation to each other in peripheral direction such that alternate coil group parts on the way to a layer situated radially further out lie radially inside the next following coil group part and alternate group parts lie radially outside the next following coil group part. Thus, on their way from position 1 in four adjacent slots 111, the coil group parts 116 run radially inside respective adjacent coil groups 117 on their way towards position 2 in four slots 111 bridging seven slots, whereas the coil group parts 117 run radially outside respective adjacently coil group parts 116. This arrangement reduces the growth of the coil end package by no less than 50%.

Figure 7 shows an embodiment of the winding according to the invention, known as stepped lap-winding. The diagram shows the winding of one phase with the cable U1. As is clear, the cable U1 starts from position 1 in slot 4, forms a coil end to position 2 in slot 11 and then forms the innermost coil in the next coil end group part by passing to position 3 in slot 4, then to position 4 in slot 11, then to position 1 in slot 3, continuing to position 2 in slot 12, and so on. Two coil end group parts are thus formed in parallel, having four coils each, the four coils bridging seven, nine, eleven and thirteen slots, respectively.

Figure 6 indicates the drawing of the cable for two coil group parts in the positions 1 - 4 in slots 1 - 4 and 11 - 14.

- 5 The stator winding according to the invention solves the problem of the large coil end package which, if previously known winding technology were used in the high-voltage machines under discussion, would be far too complicated, with a large number of intersections.
- 10 Besides the advantage of the reduced radial dimension of the coil end package, the winding according to the invention also provides a cavity which can be beneficially used to hold the coil end package. The cables vibrate during operation, and in order to avoid wear between them they must be reinforced. Regardless of whether such an arrangement is used, a pressure-distributing and
- 15 wear-preventing curable compound can be used between the cables in the coil.